RESTRICTED CIRCULATION

This paper is not an official document: it is for information only and must not be quoted in any printed publication

Agricultural Memorandum No 919

The calculation of irrigation need: some further notes on the significance of advection

by N. Thompson

1. Introduction

The traditional method of calculating irrigation need uses a combination equation such as the Penman-Monteith in conjunction with standard meteorological measurements over an unirrigated surface in order to calculate water loss from the watered crop, and combines this estimate with measured or estimated rainfall to assess the water needs of the crop. The invalidity of this procedure has not been widely discussed, but may be easily demonstrated (eg Gloster & Thompson 1979). Take for example the case where a small field is irrigated in an otherwise arid area. The routine meteorological data will have been obtained over a surface with high surface resistance, leading to a high surface temperature and specific humidity deficit. The calculation of water loss from the irrigated area assumes that a correct answer will follow from use of these latter values (temperature and humidity) in conjunction with a surface resistance appropriate to the irrigated crop. The only justification for this approach is that the consequent overestimation of the aerodynamic contribution may compensate for the advection component which the calculation ignores. That this cannot be so usually has been demonstrated in numerous experimental studies which show that evaporation decreases progressively downwind from the leading edge of irrigated plots, so that a single estimate of evaporation rate could apply at best to a single distance from the leading edge.

An investigation by Dale and Scheeringa (1977) provides some data on the errors involved in equating potential evaporation calculated from meteorological measurements over a dry area to evaporation from an adjacent moist surface. They demonstrated that a simplified version of the Penman-Monteith combination equation produced consistent estimates of losses from an evaporation pan when the surroundings were moist, but underestimated by at least 50% when available soil moisture in the top 0.15 m under the crop decreased to less than 20% of its maximum value.

Gloster and Thompson (1979) discussed various treatments of advection which in principle can provide corrections to MORECS estimates in order to allow for advective effects in droughty conditions. A detailed approach by de Vries (1959) gave plausible results, but a simpler scheme suggested to McNaughton (1976) and in a form suitable for use with MORECS unfortunately gave unrealistic results in

very dry conditions. McNaughton (1981) has recently described a scheme for estimating loss of surface moisture from an area being irrigated (zero surface resistance) and this appears to provide a useful basis for roughly estimating the advective enhancement of evaporation. This scheme and its application are discussed in the remainder of the present memorandum.

2. McNaughton's (1981) scheme

This assumes that vertical diffusion coefficients for heat, water vapour and momentum over the wetted area are all equal, fair approximations in neutral or stable conditions, but definitely untrue in unstable cases. However, these last are less likely to occur in advective conditions: indeed inversions often develop over irrigated areas located in a dry region. Power-law wind and diffusivity profiles are used instead of logarithmic ones, but the consequent errors are negligible if the powers are carefully chosen. McNaughton defined a parameter P by

$$P = r_s u_* / (1 + \Delta\lambda / c_p) \qquad (1)$$

and wrote

$$E/E' = 1 + \alpha \qquad (2)$$

with

$$\alpha = c P \left(L/z_o\right)^{-\eta} \qquad (3)$$

where

E = rate of evaporation over wetted strip of length L in downwind direction, measured from leading edge of wetted area
E' = rate of evaporation upwind of wetted area
z_o = roughness length of surface
η = function of powers assumed for wind and diffusivity profiles
r_s = surface resistance of unwetted area
u_* = friction velocity
c = 0.29 (slightly unstable)
= 0.25 (neutral)
= 0.21 (slightly stable)
c_p = specific heat of air
Δ = change of saturation specific humidity with temperature

Table 1 gives the values for α/P calculated by McNaughton for different values of c and L/z_o

Table 1 Values of α/P

c	α/P		
	L/z_o = 100	500	2000
0.29	0.16	0.13	0.11
0.25	0.15	0.12	0.11
0.21	0.13	0.11	0.10

McNaughton's results may be compared with those given by MORECS for a thoroughly wet canopy for which a zero surface resistance is assumed. Thus (with the usual notation)

$$E_{MORECS} = \frac{\Delta(R_N - G) + \rho c_p \delta q / r_a}{\Delta\lambda + c_p}$$

$$= A/(\Delta\lambda + c_p) \qquad (4)$$

The estimate of evaporation over the dry upwind area is

$$E' = \frac{\Delta(R_N - G) + \rho c_p \delta q / r_a}{\Delta\lambda + c_p (1 + r_s / r_a)}$$

$$= A/(\Delta\lambda + c_p (1 + r_s / r_a)) \qquad (5)$$

Then, from equation (2)

$$E = E'(1+\alpha)$$

$$= A(1+\alpha)/(\Delta\lambda + c_p (1 + r_s / r_a))$$

$$= E_{MORECS} \cdot \frac{(1+\alpha)(\Delta\lambda + c_p)}{\Delta\lambda + c_p (1 + r_s / r_a)} \qquad (6)$$

This last equation may be readily evaluated. Two sample calculations for the following variable values are given in Table 2.

Δ = 0.0009 deg C^{-1} (temperature = 20 deg C)

r_s = 100, 1000 sm^{-1}

z_o = 0.02 m

L = 10, 40 m

wind speed (at 2 m) = 3, 6 ms^{-1}

u_* = 0.26 (u = 3 ms^{-1}), 0.52 ms^{-1} (u = 6 ms^{-1})

r_a = 44 sm^{-1} 22 ms^{-1}

Table 2 Comparison of McNaughton and MORECS estimates

(a) $U = 3\ ms^{-1}$

r_s	P	E/E_{MORECS}	
		L = 10 m	40 m
100	8.1	1.15	1.11
1000	81	1.33	1.23

(b) $U = 6\ ms^{-1}$

r_s	P	E/E_{MORECS}	
		= 10 m	40 m
100	16.2	1.22	1.15
1000	162	1.35	1.24

3. Discussion

The results presented in Table 2 are broadly consistent with the experimental data of Dale and Scheeringa. However, they can be used only to give a rough guide to the errors attendant on using MORECS values for the estimation of irrigation requirements, because of the various assumptions used in their derivation: these include equal roughness lengths and diffusivities for heat, water vapour and momentum tranfers and similar available energies over the dry and wet areas.

A further point is that the surface cover of the irrigated area has been assumed to be wet. When it dries the surface resistance will be typically 30–50 sm^{-1}. The evaporation will then be somewhat smaller, as will be the amount of advected energy, and at first sight the percentage correction to MORECS to allow for advection would also be reduced. However, the MORECS estimate would also be smaller, a consequence of using a non-zero surface resistance: for example the ratio $E_{MORECS}(r_s=40)/E_{MORECS}(r_s=0)$ at a wind speed of 3 ms^{-1}, roughness length of 0.02 m and temperature of 20 deg C is about 0.8. It seems likely therefore that with large values for r_s over the unirrigated surroundings the advection correction to MORECS would be little changed if McNaughton's (1981) theory had been extended to include advection over an area of reduced, but non-zero, surface resistance.

Experimental and theoretical studies suggest then that in dry conditions water use by irrigated crops will exceed the MORECS estimate by several tens of percent over the upwind margins of irrigated fields: extrapolation of the results in Table 2

to larger values suggests that for short crops (0.2 m tall) the average underestimation of water use over an irrigated field 100 m or so across would probably be around 20% in very dry conditions. These are significant corrections but would require more exact experimental verification before adoption in view of the approximate nature of the theory. The usual lack of prolonged drought conditions in Britain means that the required experiments would have to be carried out abroad to provide a certainty of success.

Any comments or suggestions in this paper should be referred to the author.

Meteorological Office, Met O 8a
London Road
Bracknell
Berkshire

June 1981

References

Dale, R F and Scheeringa, K L (1977) The effect of soil moisture on pan evaporation. Agric. Met. 18, 463-474

Gloster, J and Thompson, N (1979) Advection and the estimation of irrigation need. Agricultural Memorandum No 861

McNaughton, K G (1976) Evaporation and advection II: evaporation downwind of a boundary separating regions having different surface resistances and available energies. QJ R Met. Soc., 102, 193-202

McNaughton, K G (1981) Net interception losses during sprinkler irrigation. Agric. Met. 24, 11-27

de Vries, D A (1959) The influence of irrigation on the energy balance and the climate near the ground, J. Met. 16, 256-270